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Section 4.1.3: Chironomid analysis: background, methods and geomorphological applications

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4.1.3. Chironomid Analysis: Background, Methods and Geomorphological Applications

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ABSTRACT: Subfossil chironomids can provide both qualitative and quantitative reconstructions of past climatic and environmental conditions. Chironomid data are frequently used in palaeoecological and palaeoclimate studies, however geomorphological studies using chironomid data are currently few. Chironomid records are produced from lacustrine and alluvial sediments; these terrestrially based reconstructions can be of benefit to geomorphologists. In order to increase geomorphologists' awareness of the potential of chironomid data this paper discusses the technique, with a particular focus on geomorphological applications. Chironomids and chironomid analysis are briefly introduced, and the methods used, both in the field and the laboratory, are outlined. Geomorphological studies which have utilised existing chironomid data, including glacial geomorphological, sea level and palaeohydrological studies, are discussed, as well as a chironomid study which produced data specifically aimed at investigating changing sea level. It is hoped that further applications for chironomid data in geomorphological studies will emerge.

KEYWORDS: chironomid – palaeolimnology - sea level - glacial geomorphology - floodplain – palaeohydrology

Introduction

Chironomids (Insecta; Diptera; Chironomidae), also known as non-biting midges, are a family of two-winged flies with an estimated 15000 species globally (Cranston, 1995). Chironomids are often the most abundant insect group found in freshwaters (Pinder, 1983; Cranston, 1995) and are the most ubiquitous of all aquatic species (Oliver and Roussel, 1983). Chironomids are holometabolous insects, with four life-stages (egg, larva, pupa, adult). It is the larval stage which is of interest to palaeoecologists. There are four instars of larval chironomids; each larval stage undergoes ecdysis (Oliver, 1971). The early instars do not preserve very well, but while the soft parts of the third and fourth instars tend to decay, the chitinous head capsule will preserve, recording the presence of this chironomid. The chitinous head capsules of the larvae are often well preserved and abundant in lake sediments (Walker, 2001). It is possible to obtain sediment cores from lacustrine environments and to extract and identify the chironomid head capsules preserved within them, to provide information about which chironomids used to live in an environment.

Due to the fact that chironomid species have different environmental preferences and tolerances it is possible to reconstruct past environmental conditions from the head capsule data. Key to these reconstructions is an understanding of modern ecological processes (Eggermont and Heiri, 2012; Velle *et al.*, 2012; Juggins, 2013), and a number of studies have been carried out to better understand the relationships between chironomid species and their environments (e.g., Marziali and Rossaro, 2013; Rae, 2013).

If these relationships are found to be significant statistically it is possible to produce a model which allows quantitative reconstruction of past conditions (e.g., Birks, 1995; 1998). In 2000 Battarbee stated 'The most promising biological transfer function approach for direct temperature reconstruction is for chironomids' (p112). Since then a large amount of work has been carried out and numerous chironomid-inferred temperature reconstructions produced from many parts of the world (e.g., Woodward and Shulmeister, 2007; Eggermont *et al.*, 2010; Bunbury and Gajewski, 2012; Axford *et al.*, 2013; Massaferro and Larocque-Tobler, 2013; Nazarova *et al.*, 2013; Berntsson *et al.*, 2014), with transfer functions constantly being developed and improved (e.g., Heiri *et al.*, 2011; Holmes *et al.*, 2011; Engels *et al.*, 2014; Luoto *et al.*, 2014). Other parameters, such as pH (e.g., Rees and Cwynar, 2010), salinity (e.g., Eggermont *et al.*, 2006), hypolimnetic oxygen (e.g., Summers *et al.*, 2012) and water depth (e.g., Engels *et al.*, 2012) can also be quantitatively reconstructed.

Quantitative chironomid data are frequently used in palaeoecological and palaeoclimate studies, however geomorphological studies using chironomid data are currently few. This article aims to introduce geomorphologists to chironomid analysis, outline the methods used, highlight some of the geomorphological studies which have used chironomid data and discuss how chironomid data could be further used to support geomorphological studies.

Methods

Field sampling

Key to obtaining a useful chironomid data set is obtaining reliable sediment samples to work on.

Corers

Depending on the nature of the sediments to be studied, and the focus of the study, different coring methods are used. In order to obtain a core from a lake it is nearly always necessary to have a well anchored boat or coring platform to work from. Long sequences can be obtained using piston corers (e.g., Livingstone, 1955, see Figure 1a), Mackereth corers (Mackereth, 1958), percussion, hammer or tapper corers (Reasoner, 1986; Satake, 1988; Nesje, 1992, see Figure 1b), and Russian corers (Jowsey, 1966). Shorter sequences, or the sediment-water interface required for training sets, can be taken using gravity corers (Blomqvist and Abrahamsson, 1985; Glew, 1991; Renberg, 1991). Freeze corers can also be used to obtain sediments, and are particularly useful if laminated sequences are present (Renberg and Hansson, 2010). See *Geomorphological Techniques* Section 4.1.1 for more detailed information on coring methods.

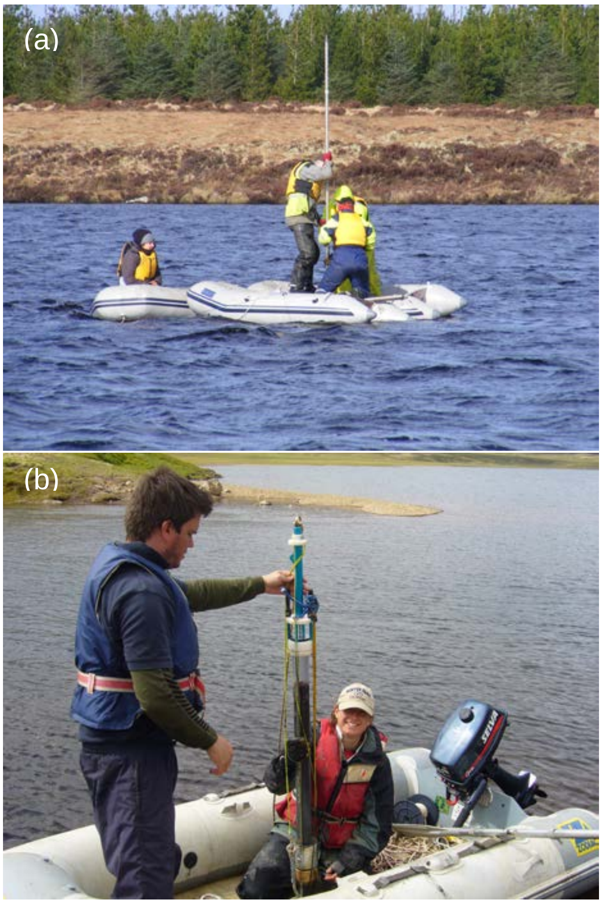

Figure 1: (a) Obtaining a core from Cregganmore, County Mayo, Ireland, using a Livingstone corer (Photo: Steve Davis) (b) Returning to shore with a tapper core from Baulárvallavatn, Iceland.

Coring locations

Due to the time consuming nature of chironomid analysis it is common for only one sediment core from a site to be analysed for subfossil chironomids; this is true for both time-stratigraphical studies and for development of a training set. It is therefore important to select the most suitable location from which to obtain a core.

A number of studies have investigated the intra-lake variability of subfossil chironomid surface-samples and whether taking one core sample from a lake is representative of the whole lake (Heiri, 2004; Eggermont *et al.*, 2007; Bunbury and Gajewski, 2008; Holmes *et al.*, 2009; Kurek and Cwynar, 2009; Luoto, 2010; 2012; van Hardenbroek *et al.*, 2011; Heggen *et al.*, 2012; Zhang *et al.*, 2013). Results differ in different types of lakes, but in general it is accepted that obtaining a sample from the centre of the lake basin will allow the whole lake assemblage to be represented (van Hardenbroek *et al.*, 2011, Heggen *et al.*, 2012).

Laboratory methods

Chironomid analysis is a time consuming process (Brooks *et al.*, 2007); it can frequently take one to two days to fully analyse a single sample. Standard chironomid laboratory methods are discussed in full in Brooks *et al.* (2007), however the methods are briefly detailed here.

Sample storage

Samples do not need to be worked on immediately but must be stored appropriately. Intact cores and wet sediment samples should be stored wrapped at approximately 4°C. Samples can be dried (air, oven or freeze dried) and should then be stored in a cool dry environment.

Sample preparation

A known amount of sediment (measured as volume of wet sediment or weight of dry sediment) should be deflocculated in 10% potassium hydroxide. This should be warmed to approximately 75°C for roughly 15 minutes; the sample should be frequently stirred and should not be allowed to boil as this may cause damage to head capsules. The sample should then be sieved, and can be passed through one sieve (90 µm mesh) or, in order to allow easier sorting, through two sieves (90 µm mesh and 180 or 212 µm mesh). The sievings are washed into small pots/vials for storage, keeping the two size fractions separate if two sieves were used.

If samples are particularly high in carbonate or clay it is suggested that, following sieving, the samples are ultrasounded before being re-sieved and then washed into small pots/vials (Lang *et al.*, 2003). This has been found to significantly increase head capsule yields.

Sample sorting

The sievings from a sample are pipetted into a grooved perspex (Bogorov) sorter (Gannon, 1971). If this is not available, a scored petri dish may be used, though care must be taken to ensure all the sample is sorted through. The sorter is placed on a stereo microscope (under x20-25 magnification) with a light source and head capsules are picked out using fine forceps. The head capsules are placed into a small container filled with water (if using Hydro Matrix® mountant; other mountants may require the use of different procedures). It is good practice for all the head capsules in a sample to be picked out for identification. Ideally a sample will contain a minimum of 50 head capsules, although a sample size of 100-150 head capsules is considered to give more reliable results (Heiri and Lotter, 2001; Larocque, 2001; Quinlan and Smol, 2001). If less than 50 head capsules are found it may be necessary to prepare more sediment.

Microscope slide mounting

Hydro-Matrix® is a popular mountant used for preparing chironomid head capsule slides. It is a water-soluble, non-toxic, non-darkening, non-polluting, fast solidifying and drying permanent mounting compound (Imscope, n.d.). A drop of Hydro-Matrix® is placed onto a microscope slide. Between two to four head capsules are placed, ventral side up, into the Hydro-Matrix® drop. A 6 mm or 10 mm diameter cover slip is carefully placed on to the drop ensuring the head capsules are covered. It is possible to place six to eight drops on each microscope slide. Hydro-Matrix® takes about 20 minutes to solidify at a temperature of approximately 25°C so slides should be stored horizontally immediately after they are prepared.

Chironomid identification

A biological microscope is used for identification (x40 magnification). Chironomid head capsules (see Figure 2) are identified by using a range of keys and identification guides (e.g., Cranston, 1982; Oliver and Roussel, 1983; Wiederholm, 1983; Schmid, 1993; Rieradevall and Brooks, 2001; Brooks *et al.*, 2007; Andersen *et al.*, 2013; Larocque-

Tobler, 2014). Key characteristics, such as head capsule shape, ventromental plates, shape and number of teeth on the mentum (see Figure 2), and, if present, mandibles, are used to first categorise which subfamily a head capsule belongs to (Tanypodinae, Chironominae, Orthocladiinae, Diamesinae, Prodiamesinae and Podonominae). Following this, a key can be used to identify a specimen to as high a taxonomic level as possible. A complete head capsule is recorded as one, while an incomplete head capsule with over 50% of it present is recorded as half. Remains which comprise <50% of a head capsule are not counted.

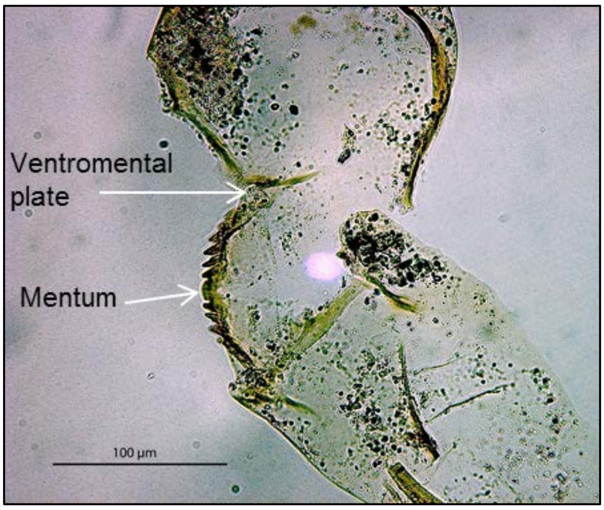

Figure 2: A chironomid head capsule.

Data presentation and analysis

Discussion of chironomid data presentation and analysis is beyond the scope of this paper; for information on these topics see Birks *et al.* (2012).

Geomorphological Applications

Although chironomid analysis is not frequently integrated into geomorphological studies, chironomid data have been used by some geomorphologists. The quantitative reconstructions produced by chironomid studies provide an independent record which can be used to help support geomorphological studies (e.g., Benn and Ballantyne, 2005; Giguet-Covex *et al.*, 2012; Doughty *et al.*, 2013). Chironomid data are also produced with the primary aim of informing geomorphological investigations (e.g., Dickson *et al.*, 2014).

Glacial geomorphology and palaeoclimate

Geomorphological mapping of past (Younger Dryas) glacier extent has been carried out in many parts of Scotland (e.g., Cornish, 1981; Ballantyne, 1989; 2006; Finlayson, 2006). Past Equilibrium Line Altitudes (ELAs) have been estimated; along with a past temperature estimate these can be used to calculate palaeoprecipitation using modern relationships between temperature, precipitation and ELA. Ballantyne (2002) suggested that an independent proxy palaeotemperature record could provide the estimate of past temperature. However it was thought that the Whitrig Bog chironomid record (Brooks and Birks, 2000), the only independent proxy temperature record for Scotland, was located too far away from the study location to be representative (Ballantyne, 2002). Further work used the Whitrig Bog chironomid temperature reconstruction, along with unpublished data from Abernethy forest, to calculate palaeotemperature for past regional ELAs (Benn and Ballantyne, 2005). Using these data it was possible to derive past precipitation estimates and to investigate past precipitation gradients (Benn and Ballantyne, 2005). A number of similar studies have been carried out and these have allowed for a more detailed understanding of palaeoclimate, particularly precipitation, and glacier land system behaviour in Scotland during the Younger Dryas (Benn and Lukas, 2006; Ballantyne, 2007; Lukas and Bradwell, 2010).

Doughty *et al.* (2013) used a combination of geomorphological mapping, a coupled energy-balance and ice-flow model and chironomid-inferred temperature data to evaluate late glacial temperatures and investigate the Antarctic Cold Reversal (ACR) in New Zealand. Chironomid-inferred temperature reconstructions produced by Vandergoes *et al.* (2008) were used to force the model (see Figure 3). Doughty *et al.* (2013) compared the glacier simulations produced to the mapped and dated glacial geomorphological (moraine) record of Kaplan *et al.* (2010). The simulated glacier length and the geomorphological record were found to provide consistent information about climate, and suggest that during the ACR temperatures in New Zealand were 2-3°C cooler than present day (Doughty *et al.*, 2013).

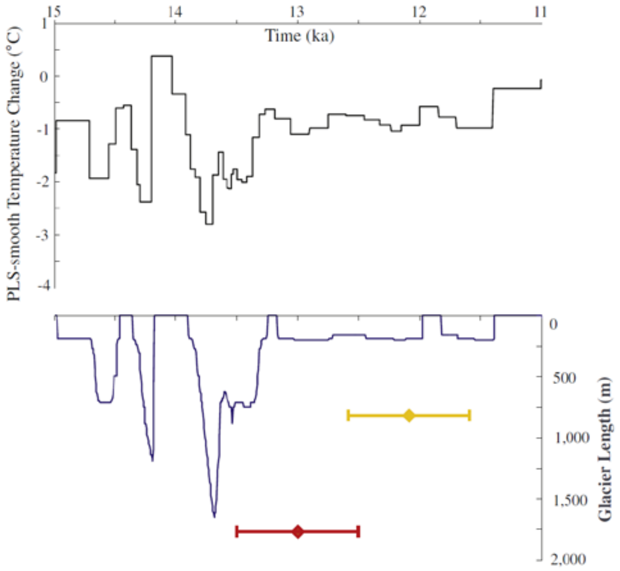

Figure 3: Chironomid-inferred temperature reconstruction (top) and modelled glacier length (bottom). Orange and yellow diamonds represent the moraine positions dated to 13.0 ± 0.5 and 12.1 ± 0.5 ka respectively. Source: Adapted from Figure 5 in Doughty et al. (2013).

Sea-level change and isostatic uplift

Subfossil chironomids can be used as indicators of salinity (Heinrichs and Walker, 2006). It is possible to both qualitatively and quantitatively reconstruct past salinity and these records can provide information about past sea levels (Heinrichs and Walker, 2006).

Solem *et al.* (1997) analysed sediment cores from coastal lakes in Norway in order to investigate invertebrate colonisation following isolation and uplift. It was possible to estimate the timing of isolation and the timescale over which the saline water was replaced by freshwater. At one of the sites it was estimated that this occurred within a 40 year time period (Solem *et al.*, 1997). Hofmann and Winn (2000) analysed a number of sites in the Western Baltic Sea in order to study the Littorina marine transgression. Before the transgression, the sites studied were separate freshwater bodies, which supported a diverse chironomid fauna (see Figure 4) (Hofmann and Winn, 2000). Following the transgression the sites supported three chironomid fauna *(Clunio marinus, Chironomus salinarius* and *Cricotopus/Halocladius)*, all representative of brackish environments (Hofmann and Winn, 2000).

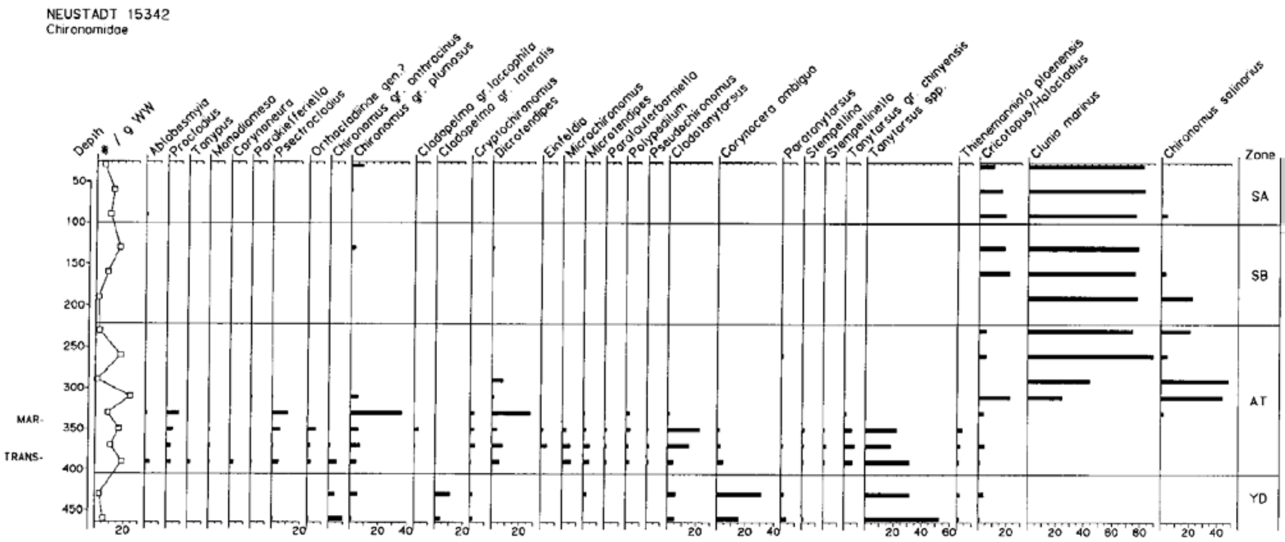

Figure 4: The Neustadt Bay (core 15342) chironomid percentage diagram showing changes in chironomid assemblages through the core. Freshwater assemblages are present in the lower samples, before an assemblage indicative of brackish water (Clunio marinus, Chironomus salinarius and *Cricotopus/Halocladius) appears. TRANS indicates the position of the transgression horizon. MAR indicates the onset of marine conditions. Zone reflects pollen zones (YD – Younger Dryas; AT – Atlantic; SB – Subboreal; SA – Subatlantic). Source: Figure 2 in Hofmann and Winn (2000).*

Rosenberg *et al.* (2005) produced a quantitative chironomid-inferred salinity reconstruction and discussed this in the context of past coastal emergence and submergence, suggesting that the record provided useful information about basin isolation from the sea. It is thought that a short-lived peak in salinity may be the result of marine incursion (by a storm surge or tsunami) (Rosenberg *et al.*, 2005), suggesting palaeo-tsunamis could be investigated using chironomid records from coastal locations. Cranston (2007) studied the impact of the 2004 Indian Ocean tsunami on aquatic habitats in coastal south west Thailand on chironomids. Studies such as this could help inform palaeo-tsunami studies.

Dickson *et al.* (2014) developed a chironomid-salinity transfer function with the specific purpose of investigating sea-level change due to isostatic uplift. The next steps in their research will apply this transfer function to four long cores in order to produce reconstructions of sea level in the Hudson Bay lowlands, an area which has experienced relatively recent isostatic rebound which continues today (Dickson *et al.*, 2014).

Palaeohydrology

Most subfossil chironomid studies are carried out on lacustrine deposits, however many chironomids are found in rivers (Pinder, 1995) and alluvial deposits offer an opportunity for the study of subfossil chironomids. Gandouin *et al.* (2005) undertook a study of chironomids in floodplain deposits. Chironomid taxa were classified into three categories: lentic habitat taxa (associated with oxbows or temporarily connected side arms); lotic habitat taxa (associated with the main channel or connected side arms; and other chironomids (includes taxa which could not be fully identified and taxa whose distribution is unknown or not related to current flow rate). Gandouin *et al.* (2006) introduced a fourth category 'ubiquitous taxa'. Using these classifications it was possible to qualitatively reconstruct past hydrological conditions and river morphology, including past connectivity (Gandouin *et al.*, 2005, 2006, 2007). In a study of the lateglacial-Holocene transition Gandouin *et al.* (2007) found a shift in chironomid taxa from cold-water adapted and rheophilous (lotic) taxa to warm-water adapted and limnophilous (lentic) taxa, as the river switched from a braided to a meandering system (see Figure 5). Chironomids can be a useful technique for reconstructing palaeoenvironmental change in river floodplains due to the fact that they are influenced by hydrological changes, which are often induced by climatic changes (Gandouin *et al.*, 2007).

Existing chironomid data have also been used to inform palaeo-hydrological studies. Giguet-Covex *et al.* (2012) compared a palaeo-flood reconstruction with a chironomid-inferred temperature reconstruction (Millet *et al.*, 2009) from the same core. This enabled relationships between flood intensity and temperature to be investigated (Giguet-Covex *et al.*, 2012); with the finding that floods of higher energy generally occurred during periods of warmer temperatures.

Potential applications

The ability of subfossil chironomids to reconstruct a number of variables such as air temperature, lake water depth, and salinity suggests that chironomids can provide useful palaeoenvironmental data which can be used in geomorphological studies. As well as providing long timescale data, chironomids may also be able to provide information about short-lived events, such as past storm surges and tsunamis (Heinrichs and Walker, 2006), and palaeofloods (Gandouin *et al.*, 2006).

Recently, humans have become important agents of geomorphological change (Lóczy and Sütő, 2011). Chironomids have been found to respond to changing amounts of fine sediment (Angradi, 1999). As land use changes and erosion increase, sediment and organic matter inputs into streams and rivers will vary, potentially causing a change in the chironomid record (Angradi, 1999). Chironomid analysis has the potential to identify human activity and its impacts on lacustrine and fluvial sites (e.g., Cohen *et al.*, 2005; Cao *et al.*, 2013; Zhang *et al.*, 2013; Frossard *et al.*, 2014).

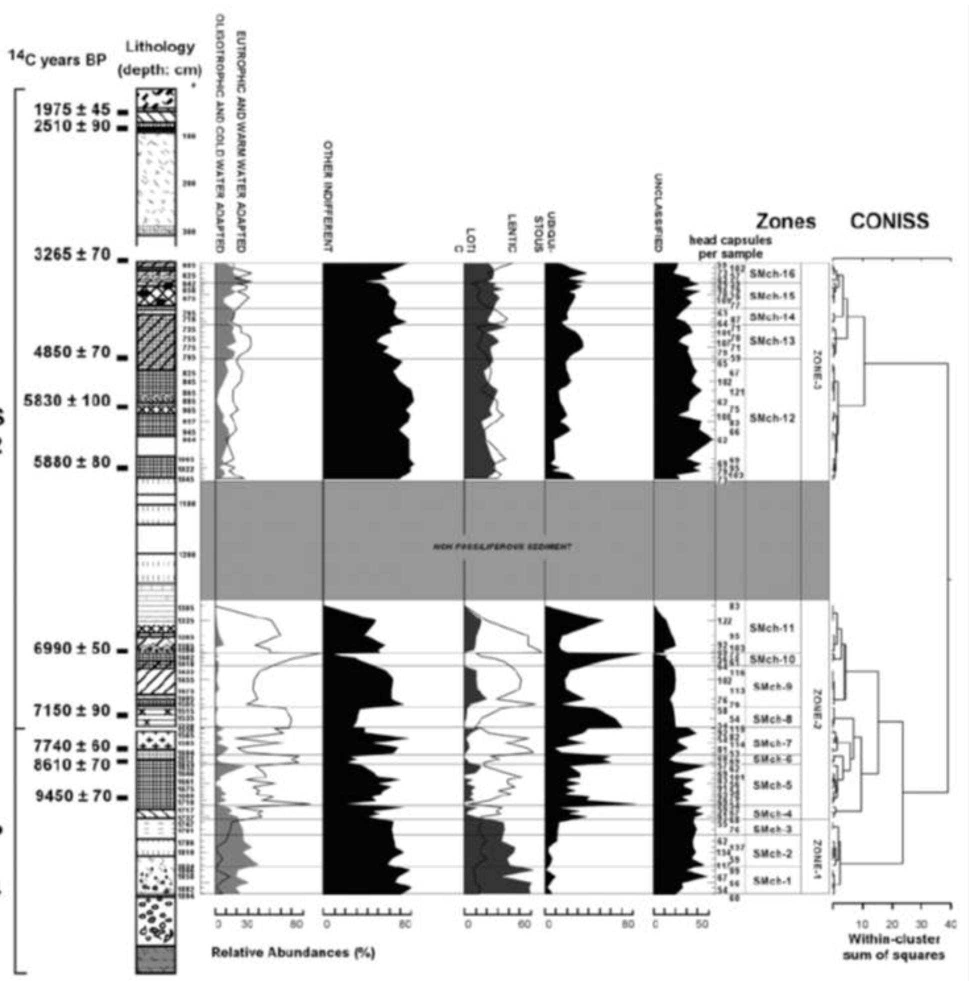

Figure 5: Synthesis diagram showing relative abundances (%) of cold-water adapted, warm-water adapted, eurythermous, lotic, lentic, ubiquitous and other unclassified taxa vs. depth. There is a shift from cold-water adapted lotic taxa to warm-water adapted lentic taxa as the river system changed from braided to meandering. Source: Figure 5 in Gandouin et al., (2007).

It is hoped that, as more geomorphologists become aware of the potential of chironomid and other palaeoecological data, both qualitative and quantitative, more interdisciplinary studies will be undertaken, particularly contributing to the improved understanding of geomorphological processes in the Holocene, a time period for which limited environmental data are available.

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